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ABSTRACT (*Maximum 200 words*)

Earlier work has shown that the acceleration sensitivity of contoured SC-cut quartz resonators vanishes for perfect symmetry of the resonator plus support system. Since it is impossible to construct such a configuration in practice, a stiffened structure which reduces the increase in acceleration sensitivity with fabrication error has been investigated. Calculations of the increase in acceleration sensitivity with fabrication error have been performed. The calculations reveal that a rectangular support configuration with an aspect ratio of 1.5 oriented in a specific direction yields optimal results. The calculations also show that two clips should be used on each of the large sides with one on each of the small sides. Optimal clip sizes and spacings between the clips were established. The use of this stiffened configuration should enable consistently low acceleration sensitivities to be obtained. Analyses of flat and contoured quartz resonators with beveled edges have been performed. The influence of the contouring and the beveling on the radial dependence of the modes was obtained.

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1. "An Analysis of the Normal Acceleration Sensitivity of Contoured Quartz Resonators Stiffened by Identical Top and Bottom Quartz Cover Plates Supported by Clips," Y. S. Zhou and H. F. Tiersten, Proceedings of the 45th Annual Symposium on Frequency Control, U.S. Army Electronics Technology and Devices Laboratory, Fort Monmouth, New Jersey and Institute of Electrical and Electronics Engineers, New York, IEEE Catalog Number 91CH2965-2, 298-308 (1991).
2. "On the Normal Acceleration Sensitivity of Contoured Quartz Resonators Stiffened by Quartz Cover Plates Supported by Clips," Y. S. Zhou and H. F. Tiersten, Journal of Applied Physics, 72, 1244-1254 (1992).
3. "The Influence of the Radius of the Contour on the Orientation of the Zero-Temperature Contoured SC-Cut Quartz Resonator," D. S. Stevens and H. F. Tiersten, 1991 Ultrasonics Symposium Proceedings, IEEE Catalog Number 91CH3079-1, Institute of Electrical and Electronics Engineers, New York, 505-510 (1991).
4. "An Analysis of the In-Plane Acceleration Sensitivity of Contoured Quartz Resonators Stiffened by Identical Top and Bottom Quartz Cover Plates Supported by Clips," Y. S. Zhou and H. F. Tiersten, Proceedings of the 1992 IEEE Frequency Control Symposium IEEE Catalog Number 92CH3083-3, Institute of Electrical and Electronics Engineers, New York, 614-625 (1992).
5. "In Plane Acceleration Sensitivity of Contoured Quartz Resonators Stiffened by Quartz Cover Plates Supported by Clips," Y. S. Zhou and H. F. Tiersten, Journal of Applied Physics, 74, 7067-7077 (1993).
6. "An Analysis of Transversely Varying Thickness Modes in Quartz Resonators with Bevelled Cylindrical Edges," H. F. Tiersten and Y. S. Zhou, Proceedings of the 1993 IEEE International Frequency Control Symposium, IEEE Catalog Number 93CH3244-1, Institute of Electrical and Electronics Engineers, New York, 431-441 (1993).
7. "Calculated Orientations and Aspect Ratios of Stiffened Rectangular Support Systems of SC-Cut Quartz Resonators Which Minimize the Influence of Fabrication Imperfections on Acceleration Sensitivity," Y. S. Zhou and H. F. Tiersten, Proceedings of the 1993 IEEE International Frequency Control Symposium, IEEE Catalog Number 93CH3244-1, Institute of Electrical and Electronics Engineers, New York, 442-447 (1993).

7. LIST OF MANUSCRIPTS - continued

8. "Transversely Varying Thickness Modes in Quartz Resonators with Beveled Cylindrical Edges," H. F. Tiersten and Y. S. Zhou, Journal of Applied Physics, 76, 7201-7208 (1994).
9. "Calculation of the Optimal Clip Dimensioning to Minimize the Influence of Fabrication Imperfections on the Acceleration Sensitivity of SC-Cut Quartz Resonators with Stiffened Rectangular Support Systems," B. J. Lwo and H. F. Tiersten, Proceedings of the 1994 IEEE International Frequency Control Symposium, IEEE Catalog Number 94CH3446-2, Institute of Electrical and Electronics Engineers, New York, 165-171 (1994).
10. "An Analysis of Transversely Varying Thickness Modes in Trapped Energy Resonators with Shallow Contours," H. F. Tiersten, B. J. Lwo and B. Dulmet, Proceedings of the 1994 IEEE International Frequency Control Symposium, IEEE Catalog Number 94CH3446-2, Institute of Electrical and Electronics Engineers, New York, 172-183 (1994).

8. SCIENTIFIC PERSONNEL SUPPORTED BY THIS PROJECT:

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BRIEF OUTLINE OF RESEARCH FINDINGS

Calculations of the influence of the radius of the contour on the orientation of the zero-temperature contoured SC-cut quartz resonator have been performed[3]. These calculations correct earlier calculations in which an error was found. These revised calculations show that not only do the magnitudes of the angles change, but the signs do also. The revised calculations are in conformity with measurement.

Earlier work has shown that both the normal and resultant in-plane acceleration sensitivities of contoured quartz resonators vanish for perfect symmetry of the resonator with respect to the support system. Since it is impossible to construct a perfectly symmetric resonator plus support configuration in practice, a stiffened structure which significantly reduces the increase in acceleration sensitivity with fabrication error has been under investigation. The structure consists of the active biconvex quartz resonator attached to identical top and bottom quartz cover plates by means of small sidewalls around the periphery. The mounting clips are attached to the top and bottom quartz cover plates without touching the active plate.

Calculations based on a variational analysis of the normal acceleration sensitivity of the stiffened configuration were performed[1,2]. The calculations reveal that increasing the thickness of the cover plates relative to the active plate reduces the normal acceleration sensitivity arising from either a misplacement of a clip or a mispositioning of the mode center. The calculations also reveal that the orientation of the support rectangle for a particular aspect ratio of an SC cut which yielded a strong minimum in the mispositioning coefficient for normal acceleration sensitivity without cover plates also yields a strong minimum when cover plates are present.

An analysis of the increase in the in-plane acceleration sensitivity of the stiffened configuration was performed[4,5]. The variational principle for the extension of thin anisotropic plates, in which all conditions appear as natural conditions, was extended to include the influence of the cover plates, the active region, the connecting sidewalls and the clips. The very important shearing deformation in the connecting regions and the sidewalls and the associated strain energy have been included in the description. The biasing deformation was calculated by means of our variational approximation procedure using the extended form of the variational principle. The calculated extensional biasing states were employed in an existing perturbation equation along with the mode shapes to calculate the increase in the in-plane acceleration sensitivity of the contoured resonator with fabrication error. The calculations reveal that the increase in the in-plane acceleration sensitivity with fabrication error is quite sensitive to the spring constants of the clips, and with proper selection can be kept quite low. The calculations also show that the optimal orientation and aspect ratio found has a resultant increase in the acceleration sensitivity with fabrication error at least four times lower than the square plate. This indicates that the circle is an undesirable shape because of its inherent isotropy.

Existing computer programs have been employed[7] in the calculation of orientations and aspect ratios of the stiffened rectangular support configuration of SC-cut quartz resonators which minimize the influence of fabrication imperfections on acceleration sensitivity. Since the earlier work established that consistently low values of acceleration sensitivity were obtained for a ratio of the thickness of the cover plates to the active plate of 2, this ratio was adhered to in all subsequent calculations. In view of the results of the work discussed above[4,5], two clips are used on each of the large sides of the rectangular configuration. Both contoured and flat plate trapped energy resonators were treated. The short distance between the sidewalls was established by a criterion associated with the energy in the mode shape of the harmonic treated. Although the square plate never yields good results, optimal and near optimal results were consistently

obtained for an aspect ratio of 1.5. Although a reasonably consistent orientation of the support rectangle is found for the contoured resonator, it varies significantly for the flat plate trapped energy resonator.

Existing computer programs have been employed[9] in the calculation of the influence of the spacing between the two clips on the longer sides, the relative sizes of the clips on the small and large sides and the thicknesses of the clips on the acceleration sensitivity of the rectangular support configuration. Since the earlier work[7] showed that an aspect ratio of 1.5 always yields optimal results, this ratio was adhered to from then on. In addition, it was shown that for contoured resonators the orientation of the rectangular sidewalls β should be between -45° and -50°. For the flat plate resonators considered the angle varied. It was also established that all clip dimensions should be the same. A range of ratio of clip size to the large dimension of the rectangle was recommended, as was a range of ratio of the spacing between the two clips on the large sides.

An analysis of transversely varying thickness modes in quartz trapped energy resonators with an electroded flat central region and contoured cylindrical edges has been performed[6,8]. A lumped parameter representation of the admittance which is valid in the vicinity of a resonance, was obtained. The resonant frequencies of some harmonics and anharmonics of both AT- and SC-cut quartz resonators were calculated along with the motional capacitances of harmonics and anharmonics which have no angular dependence. The influence of the contour on the radial dependence of the harmonic and first radial anharmonic was exhibited for the first time.

Since the existing treatments of transversely varying thickness modes in trapped energy resonators hold only either for flat plate resonators, in which the edges of the electrodes cause the trapping, and the contoured resonator, in which the edges of the electrodes are ignored in the analysis, there is a region of electrode size and radius of contour, in which both the contour and electrode edge influence the trapping, and the existing treatments cease to be valid. Consequently, an analysis of contoured resonators with rectangular electrodes, in which both the influence of the contour and the edges of the electrodes are included in the treatment, was performed[10]. Calculated resonant frequencies and motional capacitances were presented for a number of AT- and SC-cut quartz resonators. The treatment presented indicates why and when the analysis for the contoured resonator which ignores the condition at the edges of the electrodes works as well as it does. It has been shown that this treatment does not hold for the flat plate because of a loss of accuracy in the calculation. The influence of the contouring on the trapping for an electroded contoured resonator was exhibited for the fundamental and first radial anharmonic modes.